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Summary

Surgical reconstruction of torn anterior cruciate ligament has been shown to provide significant improvement in clinical outcome, compared to patients treated conservatively. However, there remains a wide scope for further improvements to attain complete restoration of patients' pre-injury level of joint health. In an effort to completely restore the normal anatomy, knee stability and to prevent the development of knee osteoarthritis, several techniques have been proposed to efficiently manage anterior cruciate ligament injuries. Controversies over which technique provides the best outcomes, however, are yet to be solved. Specifically, which surgical technique should be used to best restore the normal joint stability? Which surgical technique can most closely restore the normal anterior cruciate ligament anatomy? What are the potential adverse consequences of combined injuries on outcomes following anterior cruciate ligament reconstruction? This dissertation aims to provide objective answers to these questions through critical analysis of the existing controversies and by conducting experimental, quantitative research.

In the field of orthopaedic surgery, whether to surgically treat anterior cruciate ligament injury by single- or double-bundle reconstruction is still a major controversy. In **Chapter 2** we performed a systematic literature review and meta-analysis of biomechanical studies that compared the laxities between single- and double-bundle anterior cruciate ligament reconstructions. No statistically significant differences were found in anteroposterior laxity between these techniques at flexion angles of 0°, 30°, 60°, and 90°. One of the main reasons for the introduction of double-bundle anterior cruciate ligament reconstruction was to address the persistent rotational instability of the knee joint after conventional single-bundle reconstructions. However, among the biomechanical studies that evaluated the rotational laxities, we noticed large variations in both, experimental designs and reported measurements, which impeded the meta-analysis of this data. This leads to inconclusive evidence on the efficacies of these techniques for restoring rotational stability. Thus, the indication whether to perform single- or double-bundle anterior cruciate ligament reconstruction to achieve optimal outcomes remains unclear and more research is required to justify the need to perform a more expensive and technically challenging surgery.

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To combine the advantages of both single- and double-bundle reconstruction techniques, innovative surgical techniques that can reconstruct both the functional bundles of the anterior cruciate ligament within a single femoral and tibial tunnel have been proposed. The efficacy of single-tunnel–double-bundle anterior cruciate ligament reconstruction in restoring normal joint laxity was evaluated in **Chapters 3 and 4**. The evaluations were conducted by performing biomechanical studies using cadaveric knees and a robotic testing system. It was found that single-tunnel–double-bundle reconstruction more closely restored the increased anterior tibial translations of anterior cruciate ligament deficient knee to the normal knee level than the conventional single-bundle reconstruction. However, under physiological loading conditions, we found that both reconstruction techniques resulted in an over-constrained internal tibial rotation compared to normal knees. Such an increase in external tibial rotation has been suggested to increase patellofemoral contact pressure and altered tibiofemoral cartilage contact characteristics. Therefore, we emphasize the importance of identifying graft-tensioning strategies, which can prevent abnormal knee joint kinematics under physiological loading conditions. The ease of single-tunnel–double-bundle technique that reconstructs the functional bundles of the anterior cruciate ligament, combined with its efficacy in restoring normal knee anteroposterior laxity, provides an effective solution for the single- and double-bundle reconstruction controversy.

In addition to the choice of an appropriate surgical technique, proper positioning of the tunnels is essential for the success of anterior cruciate ligament reconstruction. Currently, there are three major arthroscopic techniques that are used to create the tunnels for anterior cruciate ligament reconstruction: anteromedial portal technique, outside-in technique, and transtibial technique. The relationship between the femoral tunnels created by these three techniques and the native anterior cruciate ligament femoral footprint were evaluated in **Chapter 5**. Further, this chapter also examined the potential for iatrogenic injury, while creating the femoral tunnels by these three techniques. This study indicated that the tunnels created by these techniques, achieve similar coverage of the entire anterior cruciate ligament and anteromedial bundle footprints. However, the amount of posterolateral bundle footprint covered by the transtibial tunnel was significantly lower than the coverage by outside-in and anteromedial portal tunnels. The center of outside-in tunnel was found to be the closest to the anterior cruciate ligament footprint center,

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followed by the center of anteromedial portal tunnel and finally the center of transtibial tunnel. The incidence of a posterior femoral tunnel exit relative to the lateral epicondyle was found to be higher when using anteromedial portal technique than either outside-in or transtibial techniques. Such a posterior location could potentially cause an injury to the lateral gastrocnemius tendon femoral attachment. Taken together, findings of this study indicate that tibial tunnel-independent techniques (anteromedial portal and outside-in) can create more anatomical tunnels than transtibial technique.

To further evaluate these techniques, their efficacy in restoring normal joint laxity and anterior cruciate ligament forces was evaluated in **Chapter 6**. The results of this study demonstrated that anterior cruciate ligament reconstruction by anteromedial portal, outside-in, and transtibial techniques results in similar knee joint laxities. However, single-bundle anterior cruciate ligament reconstruction using the tunnels created by any of these techniques could not restore the normal knee joint laxities. Similarly, anterior cruciate ligament grafts of all three reconstructions carried lower force than the native anterior cruciate ligament. Based on these findings it is evident that, although tibial tunnel-independent techniques can create more anatomical tunnels than transtibial technique, single-bundle anterior cruciate ligament reconstructions performed using the tunnel created by any of these techniques cannot completely restore normal knee laxity and anterior cruciate ligament forces. Therefore, in conjunction to creating anatomical tunnels, it is important that both functional bundles of the anterior cruciate ligament are reconstructed. This clinical need can be addressed by innovative anatomical reconstruction techniques such as the single-tunnel–double-bundle reconstruction, which provide the clinicians an effective alternative to currently practiced techniques.

Comprehensive diagnosis and appropriate treatment of concomitant injuries in an anterior cruciate ligament injured patient is paramount for the success of anterior cruciate ligament reconstruction. Objective evaluation of the effect of concomitant injuries on anterior cruciate ligament reconstruction outcomes can improve the current treatment strategies. **Chapter 7** evaluated the effect of anterior cruciate ligament reconstruction on the kinematics of the knees with combined anterior cruciate ligament deficiency and subtotal medial meniscectomy. The evaluation

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was performed in cadaveric knee specimens by measuring the knee kinematics (anterior-posterior and medial-lateral translations; internal-external rotations) using a robotic testing system. This study demonstrated that anterior cruciate ligament reconstruction in knees with subtotal medial meniscectomy cannot completely restore the normal knee kinematics. These results suggest that in knees with combined anterior cruciate ligament deficiency and subtotal medial meniscectomy, anterior cruciate ligament reconstruction alone cannot prevent alterations to tibiofemoral kinematics, thus further compounding the problems associated with isolated anterior cruciate ligament injury. Such deviations of knee kinematics from the normal state, can explain the prevalence of higher osteoarthritis rate in patients with combined anterior cruciate ligament reconstruction and meniscectomy, than in isolated anterior cruciate ligament reconstructed patients.

With the prior knowledge on the role of popliteus complex in resisting external tibial rotation, we hypothesized that untreated popliteus complex injury in an anterior cruciate ligament reconstructed knee would result in significant increase in anterior cruciate ligament graft forces under external tibial torque. This hypothesis was tested in **Chapter 8**, by measuring the kinematics and anterior cruciate ligament graft forces in cadaveric knee specimens by using a robotic testing system. In this study, external tibial rotations were found to significantly increase at all selected flexion angles due to isolated sectioning of popliteus complex compared to intact popliteus complex knee condition. This abnormal external tibial rotation caused excessive loading of anterior cruciate ligament graft at all selected flexion angles. Based on these findings, this study establishes that untreated injuries to the popliteus complex can result in subsequent failure of anterior cruciate ligament reconstructions. Therefore, prompt diagnosis of popliteus complex injury and its treatment are warranted to avert anterior cruciate ligament reconstruction failures.

Taken together, the findings of Chapters 2-8 provide objective answers to the questions set out to study in this dissertation. The implications of these findings on clinical practice and future research can be summarized as follows:

- The controversy on whether to perform single- or double-bundle anterior cruciate ligament reconstruction is a complex question that could not be

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definitively answered by the meta-analysis of the published biomechanical studies. More well-designed comparative effectiveness research is needed to comprehensively answer this question.

- Single-tunnel–double-bundle technique which can reconstruct both the functional bundles of the anterior cruciate ligament within a single femoral and tibial tunnel can be an effective alternative to both single- and double-bundle reconstruction techniques. Further optimization of this technique is required to prevent the observed over-constrained internal tibial rotation.
- Among the three tunnel creation techniques currently used for anterior cruciate ligament reconstruction, tibial tunnel-independent techniques (anteromedial portal and outside-in) can create more anatomical tunnels than the transtibial technique. However, single-bundle anterior cruciate ligament reconstruction using the tunnels created by any of these techniques could not restore the normal knee laxity and anterior cruciate ligament forces. There is no clear indication on which of these techniques is optimal for the restoration of both normal anatomy and joint stability. Therefore, it is critical to thoroughly understand the perils and pearls inherent to each of these techniques prior to clinically adopting them.
- Anterior cruciate ligament reconstruction in knees with subtotal medial meniscectomy cannot restore the normal joint laxity. This finding suggests that meniscus is an important knee stabilizer, which should be preserved to stabilize the knee joint and to mitigate the risks of joint degeneration. Currently, meniscectomy is the standard of care for irreparable meniscal injuries. Therefore, new and effective meniscal injury treatment strategies should be identified and implemented.
- Undiagnosed and hence untreated popliteus complex injury in an anterior cruciate ligament reconstructed knee results in abnormal increase in anterior cruciate ligament graft forces, subsequently leading to their failure. Therefore, prompt diagnosis of isolated popliteus complex injury and appropriate treatment is warranted to avert failure of anterior cruciate ligament grafts due to excessive loading.